DATA FUSION IN LARGE ARRAYS OF MICROSENSORS (SENSORWEB)

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Abstract

Distributed sensing by organized or self-organizing arrays of large numbers of geographically dispersed miniature sensors of various modalities is increasingly recognized as a key to battlefield surveillance. To date, research on data fusion in distributed sensing has often neglected physical constraints, including those on energy reserves, bandwidth, latency, processing capability and peak transmitter power. Fundamental limitations on data fusion and optimal strategies within these limitations, even under relative mild assumptions, are not yet known. The practical problem is that of devising algorithms that come close to the fundamental limitations with reasonable complexity. The FY2000 Multidisciplinary University Research Initiative (MURI) “Data Fusion in Large Arrays of Microsensors (Sensorweb)” will investigate these issues.

1. Introduction

Distributed sensing by organized or self-organizing arrays of large numbers of geographically dispersed miniature sensors of various modalities is increasingly recognized as a key to battlefield surveillance. In much previous and current work on distributed sensing, smart sensors with few or no constraints on power and communication bandwidth are assumed. However, for battlefield surveillance, for replacement of landmine fields and for many other applications in areas of actual or potential conflict on land and sea, it is impractical to rely on sophisticated sensors with large power supply and large communication capability. Simple, inexpensive individual devices deployed in large numbers are likely to be the source of battlefield awareness in the future.

Current designs for remote and unattended sensor arrays usually emphasize functionality of individual sensors and performance of small arrays. However, in a context of a large array of “throwaway” microsensors, each perhaps no larger than a quartz wristwatch and possessing only limited functionality, a new set of design rules is required. The power of such an array is achieved in the smart processing of numerous simple pieces of information. The data/information that will be

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14. ABSTRACT
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produced by the sensors has to be transmitted, processed and fused in a fashion that provides the commander and soldiers with reliable summary information with high probability of detection and low false alarm rates while using the minimum amount of resources. This involves discovering which set of nodes should be involved in the decision, the method by which data will be fused, the inhibition of other nodes from being involved in the decision and conveying the information to the user within the latency constraint.

To date, research on data fusion in distributed sensing has often neglected physical constraints, including those on energy reserves, bandwidth, latency, processing capability and peak transmitter power. Complex information processing systems for large arrays of microsensors will in all likelihood have unexpected coherent and emergent behaviors, including those causing unforeseen failure modes. Fundamental limitations on data fusion and optimal strategies within those limitations, even under relative mild assumptions, are not yet known. The practical problem is that of devising algorithms that come close to the fundamental limitations with reasonable complexity, latency, etc.

2. How a New Initiative in Data Fusion Was Created

In 1997, the Army Research Office and the Sensors and Electron Devices Directorate of the Army Research Laboratory began to formulate a topic in data fusion for large arrays of microsensors for the Department of Defense (DoD) Multidisciplinary University Research Initiative (MURI) program. Characteristics that make a proposed MURI topic likely to be adopted by DoD include 1) inherently multidisciplinary, 2) new area that has already passed the conjecture phase, is recognized by the community as valid but still has most of the research in front of it and 3) high payoff for the Army and the DoD.

To clarify basic research issues in this area and the connection of these issues to Army needs and to Army/DoD development programs, a Strategic Assessment Workshop "Distributed Microsensing: Devices, Networks and Information Processing" was held on January 11 and 12, 1999 at the Army Research Laboratory in Adelphi, Maryland. This workshop was sponsored by the Signal Processing Division of the Sensors and Electron Devices Directorate and the Mathematical and Computer Sciences Division of the Army Research Office (ARO), both of the Army Research Laboratory (ARL). The System Division and the Battlefield Environment Division of the ARL Information Sciences and Technology Directorate collaborated in this effort.

The objective of the workshop was to draft a report that maps out a strategy for future research and development in small, low-cost microsensing devices (acoustic, seismic, IR, magnetic, passive rf, etc.), networking of such devices and information processing for such devices. The workshop was indicative of the recognition by the Army research community of the impact that distributed microsensing will have on operational capabilities of Force XXI and Army After Next. The presentations and the discussions that took place at the workshop were the starting point for writing the Strategic Assessment Report *Distributed Microsensing: Devices, Networks and Information Processing*, which is available on the Army Research Office home page at URL http://www.aro.army.mil/mcsc/Sar_dm.htm. This report outlines 6.1-6.2-6.3 R&D in devices, networks and information processing and provides the context for Data Fusion MURI.

In April 1999, the Office of the Director of Defense Research and Engineering approved the topic "Data Fusion in Large Arrays of Microsensors (Sensorweb)" for funding under the FY 2000 MURI program and announced it to the public in a Broad Agency Announcement (BAA) in the Commerce Business Daily and on the ONR Website at http://www.onr.navy.mil/sci_tech/special/onrpgadh.htm. White papers were due on June 24, 1999. Full proposals are due on October 26, 1999. The project will start in spring 2000 and will run 3 to 5 years.

3. Objective and Research Concentration Areas of Data Fusion Initiative

The objective of the MURI "Data Fusion in Large Arrays of Microsensors (Sensorweb)" is to develop a quantitative basis for information processing in large arrays of distributed microsensors under strong limitations on the capabilities of each sensor and severe constraints on communication. To accomplish this objective, interdisciplinary research will be carried out in the following areas:

1. Determine (self-)calibration requirements and algorithms to do such calibration. Must each individual node determine its position using a GPS-like approach or can the positions be inferred (bootstrapped) using communication and processing? Must each node remember its own position, the positions of its neighbors or the positions of a large subset of the array?

2. Determine fundamental limitations on data fusion in multi-modality distributed sensing that take into account constraints on energy reserves, bandwidth, latency, processing capability, peak transmitter power and network topology. A network analogue of Shannon information theory? Random sensor distribution will probably not allow one to assume anything as simple as Internet-like nearest neighbor connections.

3. Determine the (sub)optimal trade-offs between local processing at the sensor level, processing at other levels and communication capacity, protocols, bandwidth, duty cycle, etc.; determine these trade-offs in the context of hierarchical networks with potentially more than two levels and with different communication capacities between levels.

4. Determine sensitivity and robustness to local variations in sensor density. Determine bounds for, characteristics of and algorithms for identifying the minimum number of nodes and minimum amount of resources needed to detect, estimate, classify and track an event or a collection of events at a given level of fidelity; static multiple-target separation and dynamic multiple-target tracking with network and computational constraints taken into account. Determine the dependence of algorithms on dynamic network characteristics and inter-node communication or lack thereof (as in weather-caused fade-out).

5. Design and implement data fusion algorithms that, in various metrics (perhaps including but not necessarily restricted to probability of detection and false alarm rate), come close to optimality. Compare these algorithms to alternate techniques.

6. Develop principles for describing coherent and emergent behaviors on various levels of granularity. Develop distributed control algorithms that have theoretical guarantees about global behavior. Extend verification methods such as model checking, theorem proving, and monitoring and checking. Develop methods appropriate for systems with the self-assembly, self-stabilization, adaptability, rapid reconfigurability and fault tolerance needed in distributed microsensing. Determine failure modes, especially those not expected based on experience with small arrays.

7. Create suites of events on which data fusion algorithms can be tested for closeness to optimality.

4. Impact of the Data Fusion Initiative

Many of the needs for arrays of acoustic, magnetic and seismic sensors over the next 5-10 years are outlined in Sec. IV.R.3.c of the *Army Science and Technology Master Plan* [United States Army, 1997]. The *1998 Annual Report on the Army After Next Project to the Chief of Staff of the Army* [U.S. Army Training and Doctrine Command, 1998] outlines specific Army needs for the 2025 time frame (Army After Next) that impinge on distributed sensing. Advanced data fusion techniques for large arrays of small sensors (distributed from ground vehicles, piloted aircraft, unmanned aerial vehicles and seacraft) are needed for increasingly intelligent, dynamic and precise identification of threats and for battlefield weather/condition prediction. Replacement of landmines by arrays of acoustic, IR and other small sensors is contingent upon the development of these techniques. Specific techniques that need to be developed include advanced target identification algorithms, multitarget resolution, detection and identification of impulsive acoustic signatures (for example, for sniper detection), platform and wind noise reduction techniques and compact array design for long-range acoustic detection. Monitoring of military or terrorist activity in urban areas or under heavy foliage canopy will be possible with large intelligent arrays of microsensors. Uses of data fusion in the civilian economy include security, environmental monitoring, monitoring of manufacturing networks and intelligent traffic systems.

REFERENCES

United States Army, 1997, *Army Science and Technology Master Plan, Fiscal Year 1997*, U.S. Army.

United States Army Training and Doctrine Command, 1998, *Knowledge and Speed: Battle Force and the U.S. Army of 2025, 1998 Annual Report on the Army After Next Project to the Chief of Staff of the Army*, U.S. Army Training and Doctrine Command, Ft. Monroe, Virginia, **http://www.tradoc.army.mil/dcsdoc/fbdaan/aanframe.htm** .